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VIBRATION PROPERTIES OF THE OSTRICH EGGSHELL AT IMPACT

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Abstract

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An experimental system has been used to generate the impact force, measure the response wave signal, and analyse the frequency spectrum for physical property of Ostrich eggshell. The effects of excitation point, detected point and impact intensity on the eggshell response to a light mechanical impact were analysed. The aim of this study consists in the evaluation of the main vibration properties which can be used for the detection of cracks in the eggshell. Four variables were investigated to determine if they are significant for classifying eggs by setting up relationship x- and y-coordinates, including the first dominant resonance frequency, the normalization average of the frequency domain, the average of the frequency domain, and the average x- and y-coordinates of the centroid for the frequency domain. The egg dynamic resonance frequency was obtained through the analysis of the dynamically measured frequency response of an egg excited by pendulum.

eggshell, impact, surface displacement, frequency analysis, damage

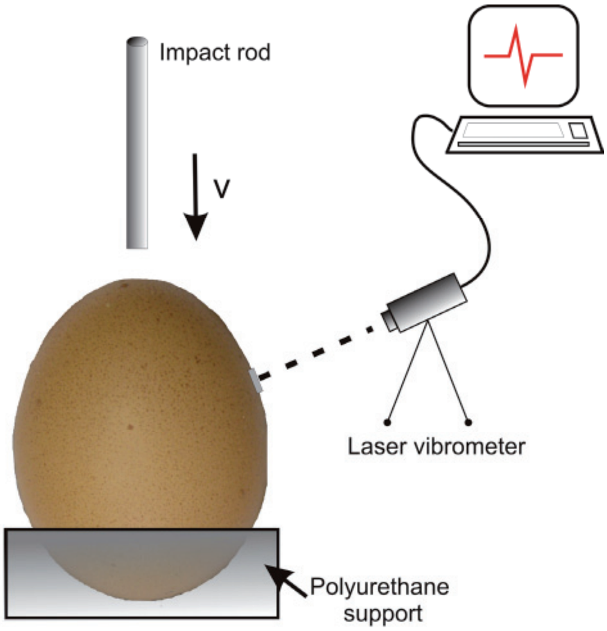
There are many methods for quality detection and sorting of agro product based on external properties such as size, shape, and external defects. One of the methods is dynamics excitation and response analysis. Dynamic excitation and response analysis is an acceptable method for determination of physical properties for quality evaluation of fresh products. Fruit response to impact and sonic excitation has been well documented in the literature for the last three decades. Many researchers have analysed acoustic impulse responses in various kinds of products (Armstrong *et al.,* 1990; Chen *et al.,* 1992; Duprat *et al.,* 1997; Hayashi *et al.,* 1995; Stone *et al.,* 1996; Sugiyama *et al.,* 1994). Most of them employed the frequency analysis technique to sound signals by means of microphone. It was observed from their researches that resonant frequencies decreased with ripening. Nevertheless, to our knowledge, dynamic excitation methods by microphone have not yet been successfully applied owing to some difficulties connected namely with the effect of the surroundings. This problem was solved e.g. by Wang *et al.* (2004). In this research, eggs were excited by pendulum on the sharp side or film sensors on the different sides the hip side or the equator, and the response signals were detected by flexible piezoelectric, respectively. Nedomová *et al.* (2009) developed a method when the specimen (egg) response has been measured using of contactless procedure.

This method has been used also in the given paper. The response wave signals were then transformed from time to frequency domain and the frequency spectrum was analysed. The specific objectives of the research were to: (1) analyse the response time signals and frequency signals of eggs, (2) evaluation of main vibration properties which enable to detect cracks.

MATERIAL AND EXPERIMENTAL METHOD

The Ostrich *(Struthio camelus)* egg has been used. The geometry and main physical properties of these eggs are described by Nedomová and Buchar (2013).

The impact loading has been performed using of the equipment described by Nedomová *et al.* (2009). The schematic is shown in the Fig. 1.



1: *Schema of the impact loading of the egg*

It consists of three major components; they are the egg support, the loading device and the response-measuring device.

The egg support is a cube made of soft polyurethane foam. The stiffness of this foam is significantly lower than the eggshell stiffness; therefore there is very little influence of this foam on the dynamic behavior of the egg.

A bar of the circular cross-section with strain gauges (semi conducting, 3 mm in length) is used as a loading device. The bar is made from aluminum alloy. Its length is 200 mm, diameter is 6 mm. The bar is allowed to fall freely from a pre-selected height *h*. The instrumentation of the bar by the strain gauges enables to record time history of the force at the area of bar-eggshell contact. The value of striking velocity, *v*, of the bar can be estimated from well known equation:

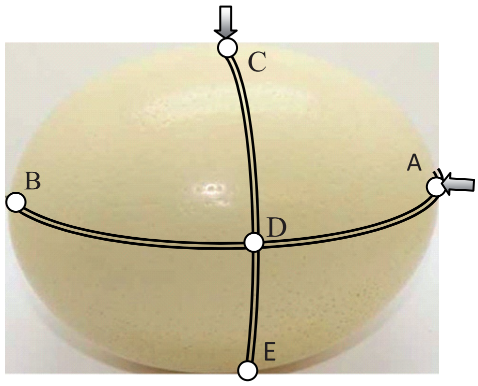
$$v = \sqrt{2gh}\,. \tag{1}$$

The verification of this equation is part of this study.

The response of the egg to the impact loading, described above, has been measured using the laser vibrometer. This device enables to obtain the time history of the eggshell surface displacement.

The eggs have been impacted on the sharp end (point A) and on the equator (point C). The values of height of the bar fall has been chosen between 100 and 900 mm. The displacement has been recorded at point D on the eggshell surface. Schematic of loading is shown in the Fig. 2.

The displacement has been measured in normal direction to the eggshell surface.



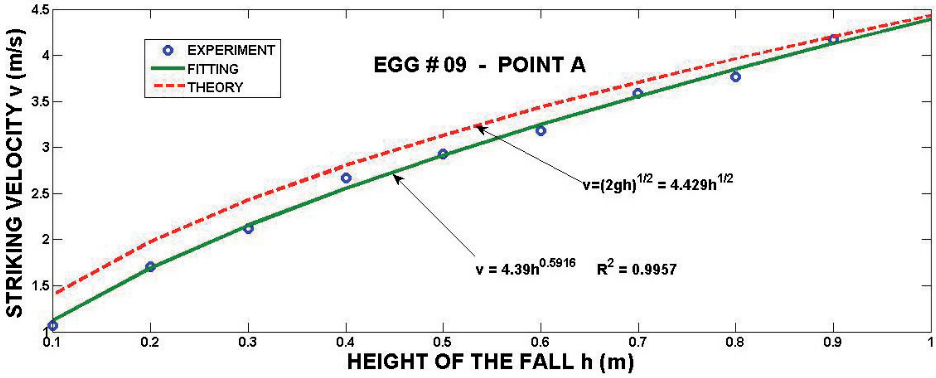
2: *Points of impact (A, B, C) and points of the surface displacement detection. (AD = 65 mm, CD = 55 mm, BD = 55 mm). Point A represents a sharp end of the egg, radius of the curvature R_1 = 50.06 mm. Point B corresponds to the blunt end of the egg, R_2 = 45.75 mm. Point C point on the surface at the maximum of the egg width, R_3 = 97.22 mm.*

RESULTS AND DISCUSSION

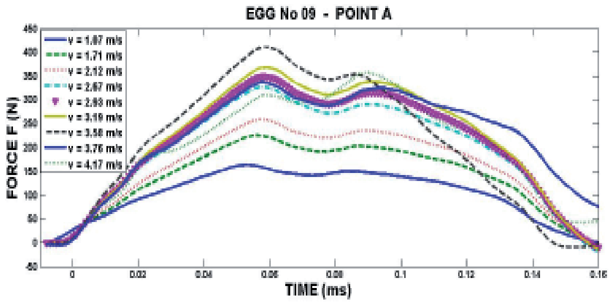
In the Fig. 3 the dependence of the striking velocity, *v*, on the height of the bar fall, *h*, is plotted.

One can see that owing to some friction effects the experimental value of the striking velocity lies below its theoretical value. It means this velocity must be measured. We used small commercially available laser module including optics with a power output level of roughly 5mW. Interruption of laser beam by the falling striker was detected by PIN diode. History of the diode signal gave us the velocity of the striker closely before the impact.

In the Fig. 4 the experimental records of the force – time at the impact point A are displayed.



3: *Striking velocity vs. height of the bar fall. Broken line corresponds to the theoretical dependence given by equation presented in the previous chapter.*



4: *Experimental records of the time history of the force at the bar impact*

The course of the force, F, – time, t curves can be represented by four parameters:

- Maximum value of the force, $F_{m.}$
- Time of the maximum force achieving, $t_{I.}$
- Time of the pulse F(t) duration, λ.
- Impulse $I = \int_0^{\lambda} F(t)dt$.

The values of these parameters are given in the Tab. I.

The effect of the impact velocity and the point of the impact on the maximum of the loading force are shown in the Fig. 5.

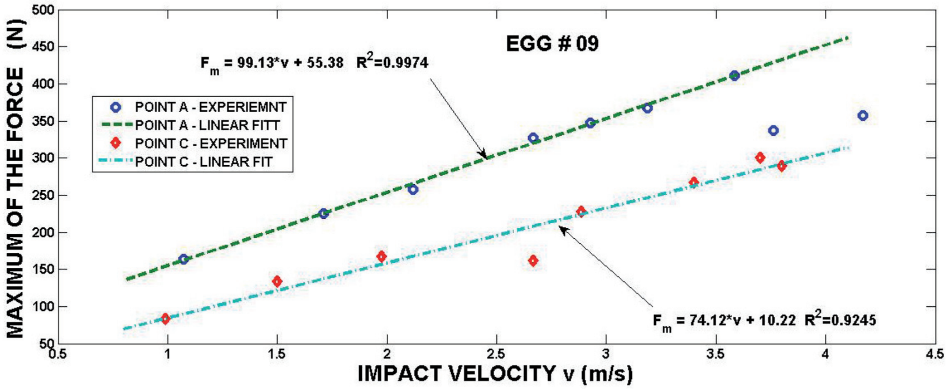
The maximum of the loading force increases linearly with the impact velocity. This conclusion is valid only for non-destructive impact. At the impact velocities 3.76 and 4.17 $m.s^{-1}$some eggshell damage occurs. The example of this damage is shown in the Fig. 6.

The maximum of the force increases with the eggshell curvature 1/R (R is the radius of the curvature). The values of R are given in Nedomová and Buchar (2013). At the point A is R = 45.63 mm and at the point C, R = 88.24 mm. This in qualitative agreement with the Hertz's contact theory (Timoshenko and Goodier, 1975).

In the Fig. 7 the time histories of the surface displacement around the meridian are shown. This displacements corresponds to the surface wave propagation from the point of the bar impact.

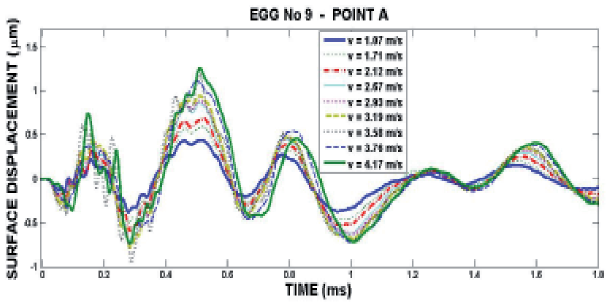
I: *Parameters of the loading force pulses*

v ($m.s^{-1}$)	F_m (N)	t_I (s)	λ (s)	IMPULSE (Ns)
1.07	163.58	0.000061	0.00017	0.017146982
1.71	224.64	0.000061	0.000163	0.023013196
2.12	258.18	0.000063	0.000165	0.02644661
2.67	326.52	0.000062	0.00016	0.032484155
2.93	347.72	0.000061	0.000161	0.034240333
3.19	367.66	0.000061	0.000159	0.035940983
3.58	411.00	0.000061	0.00015	0.034450898
3.76	336.65	0.00006	0.000182	0.036180973
4.17	356.90	0.000091	0.000183	0.032876808



5: *Maximum of the loading force*

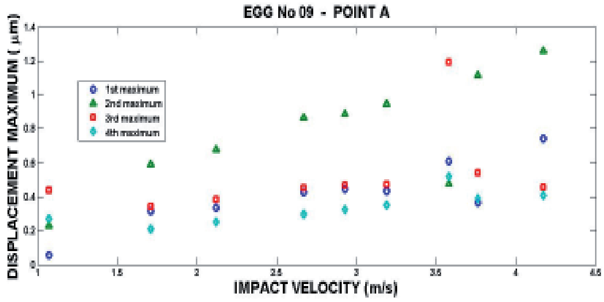
6: *Eggshell damage at the point A. Impact velocity 4.17 m.s⁻¹.*



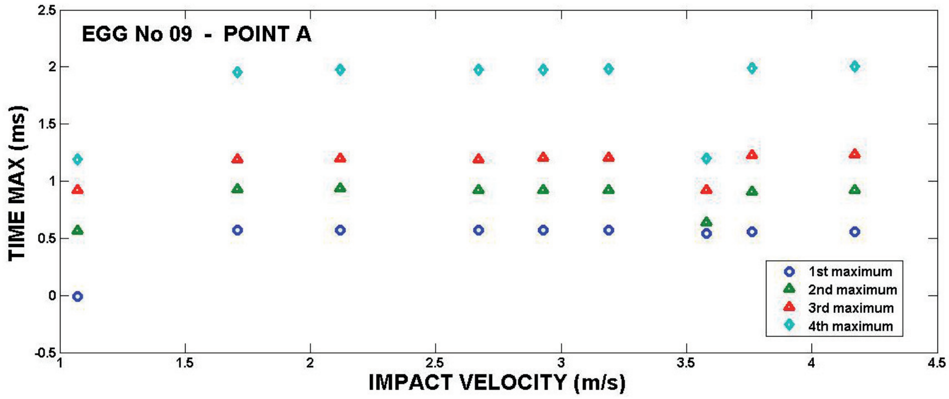
7: *Surface displacement of the eggshell loaded at the point A*

The displacement is characterized by many peaks. The values of the first four peaks are displayed in the Fig. 8.

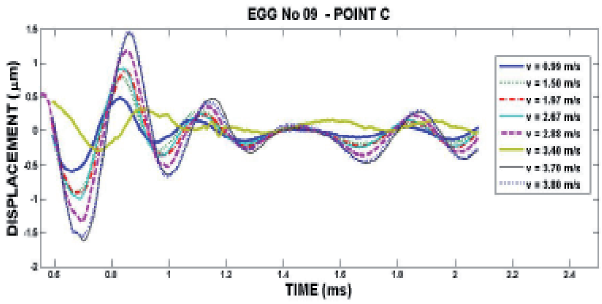
The time at which the peak is achieved is probably independent on the impact intensity as shown in the Fig. 9.



8: *The effect of the impact velocity on the peak values of the surface displacements*



9: *The times at which surface displacement exhibits a peak value*



10: *Surface displacement of the eggshell loaded at the point C*

The displacements corresponding to the bar impact at the point C exhibit very similar qualitative features as in foregoing case – see Fig. 10.

These displacements exhibits more pronounced damping than that shown in the Fig. 7.

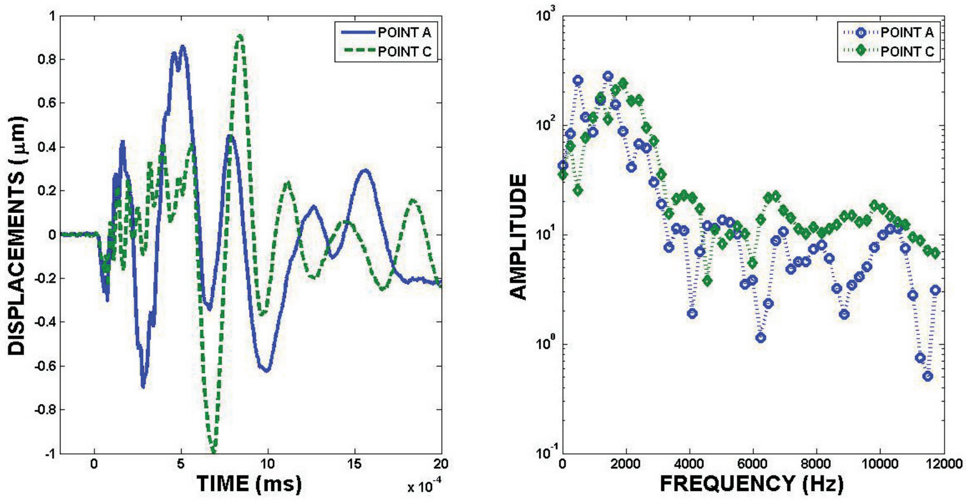
Generally the surface displacement of the egg to the bar impact is significantly affected by the position of excitation point and impact intensity. This is valid for the eggshell response in the time domain.

In the next step the forces and response (surface displacement) have been transformed from time to frequency domain by means of fast Fourier transform (FFT) using of the MATLAB software, as illustrated in Fig. 11.

The frequency response function exhibits a maximum at the frequency which is denoted as resonant or dominant frequency (Wang *et al.*, 2004). Its value, ω_{max} is then used to calculate the dynamic eggshell stiffness (k_{dyn}). Modelling the egg as a mass-spring system, the dynamic stiffness k_{dyn} is given as:

$$k_{dyn} = mw^2_{max}, \qquad (2)$$

where m is the egg mass. In the Table II. the values of the dominant frequencies determined at the point D are given. The dominant frequency is not significantly affected by excitation velocity (height of the fall). At the same time this frequency is significantly affected by the position of the point of the excitation. This conclusion is not valid for chicken eggs (Wang *et al.*, 2004).The experimental results confirm that the eggshell strength is a function of the dynamic stiffness (De Ketelaere *et al.*, 2002). The eggshell is than significantly dependent on the



11: *Typical time signal and frequency signal at the different excitation points. Left part – time signal. Right part – frequency signal of response. Egg No 9, striking velocity v = 2.67 m.s⁻¹.*

II: *Dominant frequencies f_{max} and corresponding amplitudes P_{max}*

POINT A			POINT C		
v (m.s⁻¹)	f_{max} (Hz)	P_{max}	v (m.s⁻¹)	f_{max} (Hz)	P_{max}
1.07	478.9	126.3	0.99	1197.3	125.3
1.71	478.9	132.1	1.50	1197.3	135.8
2.12	478.9	172.9	1.97	1197.3	143.5
2.67	478.9	203.0	2.67	1197.3	162.7
2.93	478.9	255.2	2.88	1197.3	176.4
3.19	478.9	267.5	3.40	1197.3	248.2
3.58	478.9	288.8	3.70	1197.3	240.4
3.76	478.9	296.9	3.80	1197.3	323.4
4.17	478.9	312.0			

loading orientation (Altuntas and Sekoroglu, 2008). Owing to this fact the dominant frequency should be dependent on the point of loading. It means results obtained by Wang *et al.* (2004) should be re-examined.

For the next analysis the four frequency features have been used (Wang and Jiang, 2005): the normalization average of the frequency domain (defined by (3)), the first dominant frequency that is the frequency of the highest peak (defined by (4)), the average x- and y- coordinates of the centroid for the frequency domain (defined by (5) and (6), respectively):

$$\bar{P} = \frac{P}{n \max\{P_i\}}, \quad (3)$$

$$f_{max} = f(P_{i,max}), \quad (4)$$

$$D_x = \frac{1}{P}\sum_{i=1}^{n} P_i f_i , \quad (5)$$

$$D_y = \frac{1}{F}\sum_{i=1}^{n} P_i f_i , \quad (6)$$

where P_i is the magnitude at the its frequency point f_i, F and P are respectively the sums of frequency values and magnitudes of the frequency domain, defined as follows:

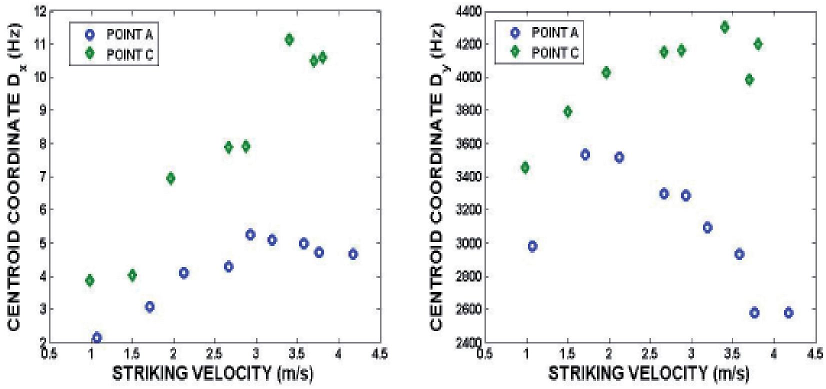
$$F = \sum_{i=1}^{n} f_i,\ P = \sum_{i=1}^{n} P_i .$$

The x and z coordinates of the centroid are shown in the Fig. 12.

The values of these coordinates are higher if the loading is performed at the Point C. In this case the coordinates are also more significantly dependent on the striking velocity than in the second case.

CONCLUSIONS

The response of the ostrich eggshell to non destructive impact has been studied. It has been found that the maximum of the force pulse is dependent on the height of the bar fall (i.e. on the



12: *Coordinates of the centroid*

impact velocity) and on the surface curvature. The maximum of the loading force is linearly dependent on the striking velocity. The surface displacement of the eggshell is significantly affected by the position of excitation point and impact velocity.

The egg dynamic resonance frequency was detected, obtained through the analysis of the dynamically measured frequency response of an excited ostrich egg. The response of the egg was very similar to that reported for the chicken eggs. The frequency spectrum is characterized by a dominant frequency. This frequency is not affected by the striking velocity but it depends on the point of the eggshell excitation by the bar impact. It means the question if the mechanical behaviour of the eggshell can be described using of the dynamic stiffness must be verified by next experiments. The response of the eggshell to the bar impact is also described in terms of centroid coordinates. It has been found that these coordinates depend on the position of the point of eggshell excitation. The results have been evaluated namely for the non-destructive impact. Their extension for the detection of the eggshell damage will be subject of the forthcoming papers.

SUMMARY

The paper deals with the research of the Ostrich's eggshell to the impact by an aluminium cylinder on the sharp side (point A) or the equator (point C). The response signals (eggshell surface displacements) were detected by laser vibrometer at the point D on the eggshell equator. The loading force is dependent on the bar striking velocity and on the eggshell curvature at the point of the bar impact. The dependence of maximum of the force F_m on the striking velocities v is described by the following equations:

$F_m = 99.13v + 53.38$ $R^2 = 0.9974$ (POINT A),
$F_m = 74.12v + 10.22$ $R^2 = 0.9245$ (POINT C),

These equations are valid only for non-destructive impact.

The response of the eggshell has been evaluated in terms of the surface displacement. The evaluation has been performed both in the time and frequency domain. The surface displacement of the eggshell in time domain is significantly affected by the position of excitation point and impact velocity. The displacement at the given point exhibits an oscillating character when some attenuation can be observed. This attenuation is more rapid if the egg is impacted at the point C on the eggshell equator.

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